



HOLISTIC SELF-REPROGRAMMING OF NEURAL NETWORKS: BETWEEN SELF-ORGANIZATION AND SELF-OBSERVATION

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Abstract: *Neural networks (NNs) are inspired – at least metaphorically – from biological solutions nature selected by evolution. On one hand, learning algorithms' efficacy has been widely demonstrated experimentally, even if the mathematical proof of their convergence is not always very easy to establish (SOM). On the other hand, biological mechanisms like brain wiring or embryology remain partly understood and how life or the bases of consciousness are related to the underlying biological substrate remains a total mystery. The same goes for memory. We don't really know how information is stored in and recovered from biological neural structures. We therein paradoxically use complex systems, the hard core of which we still don't always fully understand, both regarding the models we build, as well as their former roots in the leaving world. In this theoretical paper, we resort to a few biological encoding schemata that bring insights into neural structures' growth, plasticity and reorganization, and we suggest reconsidering the metaphor in an adaptive developmental view.*

Keywords: *Learning, memory, plasticity and adaptation, self-organizing maps, stem cells, meiosis growth, entelechy, darwinian evolution.*

1. TOWARDS A WHOLE DYNAMIC SYSTEM

This paper concentrates on the theoretical groundings of an approach of how to achieve a more general conception of learning and training methodology, detached from specialized NN models. Our main research concern is to model and simulate the dynamic character of learning structures and processes, and their evolution in the time course.

Only theoretical aspects of cumulative learning, emergent evolution, developmental structures, self-organization and the links with cellular growth we have considered to design the mechanisms of developmental learning in our system are discussed here.

In this section, we briefly set the stage we have reached with regard to our global project. In the following of the paper, we first specify the philosophical and related biological trends we subscribe to in order to draw our general scientific affiliation frame. We therein bring out the fundamental principles that, in our view, broadly characterize the development of biological encoding structures.

From this standpoint, in further consideration to the experimental literature, we try to derive some

essential underlying processes and how they intimately entangle in space and time to develop (build and maintain) the structural bases of automatic cumulative learning.

1.1 LEARNING

Among unsupervised NN models, the pioneer algorithms that are ART, SOM and NeoCognitron have now given rise to many variations around their former models. We consider the diversity of applicative and experimental contexts as similar to a selective pressure of the environment that generates a dynamic adaptation of the algorithms. Perhaps the most striking phenomenon is an obvious tendency to hybridization between models.

We resort to the evolution of natural — and mostly biological — systems, to set out to elaborate automatic and incremental knowledge acquisition strategies. In turn, we try to apply them to the NNs. We regard the primitive extractors as dynamically adaptive artificial self-organizing structures, which are submitted to the power of evolution. We examine the possibility to confront NN models to themselves. We use their own observation to lead them to learn, by themselves, the relation between their own configuration parameters and the

appropriate structuring for a given problem. This way we try to endow NNs with the ability to extract and self-learn the characteristics of their own evolution in response to environmental variations. We call our system SOH, for self-observing heuristic [26]. Our main assumption is that a dual event-guided growing competitive NN architecture can develop while learning to tune other NNs' parameters. Data driven programming combined with error measures create a self-supervision loop. The system can thus regularly test its efficiency and revert to learning mode when necessary.

The learning algorithm's skeleton has been described in details in previous reports and papers, see [27]. It is related to the SOM model and to more general map models that are able to develop their structure in time. It is currently undergoing implementation and tests. Results will appear in later reports.

We have chosen SOM because it gathers many of the elementary characteristics we review hereafter. The underlying biological metaphor is a cortical projection map. The similarity space is a dynamic pattern of connections based on activation states of the nodes, where intra-category similarities are amplified and inter-category similarities are attenuated. Hereafter, we will assume that SOM is known. We will just briefly focus on a few key properties of the model, and refer to [18] and [19] for an entire description.

1.2 DATA ACQUISITION

Besides this work, we devised a method to classify linguistic patterns extracted from documents into syntactic and semantic classes. It is an incremental text-based process flow founded on the distributional hypothesis from the Prague linguistic school. Training data are exclusively the distributional frequencies of character strings, as they represent grammatical items in texts, without any pre-specified rules. The output is a conventional SOM topology, *i.e.* an ordered bi-dimensional decomposition of the similarity relations found between grammatical items. A detailed description of the system, its theoretical foundations and results for the French language have been presented in [5], [6], [28], [29].

Further developments will attempt to gather both systems to realize a whole dynamic system from data acquisition to permanent learning and investigate its portability to other, alphabetically organized, languages. We are currently considering Greek and Arabic.

2. DEVELOPMENTAL ADAPTATION

In light of the former current initiated by

Piagetian constructivism and the principles of equilibration and adaptation in change, we will here get closer to F. Varela's concept of enaction [37] [38] as productive action, to G. Edelman's neural group theory, and to universal Darwinism.

Complex adaptive behaviors are frequently observed in nature. Systems that exhibit such organizational behavior range from particles, cells, organs, organisms, immune systems, central nervous systems (CNS), societies, to galaxies, etc. In those systems, adaptability emerges from nonlinear spatiotemporal interactions among a large number of elementary components¹ or clusters of components assembled in subsystems. To be able to acquire complex behaviors, systems must be open systems. That is to say, components must have temporal interactions with their environment and internalize a more or less elaborated trace of these interactions. As a consequence, the internalization process actively redraws — spatially — the structure of the system in such a way that the new system becomes the system itself. The system's response thereby performs an environmentally driven self-reorganization, down to the unit level.

2.1 DARWINIAN EVOLUTION

To achieve this, the efficient solution nature has elaborated is evolution. Natural selection is the motor. It guides evolution and acts as a sort that makes the structure emerge. Its origin is set in its environment. "*It is natural selection itself that enters inside the organism*" ([20], p. 63). DNA is the diversity random generator.

Investigating NNs variations in the light of Darwinian evolution leads to consider learning algorithms as open relational entities more than independent entities. From then on, learning becomes an active transmitter between open systems, agents, units or individuals, depending on the point of view we have. The process is active in the sense that it doesn't only store information inside a predefined innate structure, but it also permanently reorganizes the structure under relational constraints.

Constraints are of two kinds. The first is internal to the system and refers to the spatial arrangement of its structure. That is to say how each unit relates to the others. The second type concerns the temporal organization of the system (how it keeps the history of its confrontation with the universe it perceives).

The result is somewhat different from a sequence of chronologically ordered events. It is rather a kind of motif matching where, as in music, the last event creates, triggers a sense, which brings in light the whole set of related anterior and current events. The

¹ We will hereafter equally use the terms units, nodes neurons or cells to refer to either natural or artificial elementary constituents of the systems.

organization is not mechanistic. Cause doesn't necessarily chronologically precede effect. Positive retroaction loops can amplify the cause by re-injecting the effect into the process *i.e.* create an autocatalytic reaction. The system's evolution is thus not reversible in time. Moreover, it presents an extreme sensitivity to initial conditions. Rather close initial states can lead to very different trajectories of the system. It follows that we must consider these systems from a dynamic point of view, *i.e.* study their evolution in the course of time.

This implies reconsidering NNs' dynamics at every organization level. These range from units to models, including learning rules and heuristic choices made in implementations and configuration parameters.

2.2 SELF-ORGANIZATION

Natural systems displaying elaborated structures are not limited to the organic world. Inorganic matter too presents global organization states that exhibit proprieties, either qualitatively different from those seen at the local level, or even new proprieties absent at the local level. Typical examples of non-biological self-organization are, among many others, the Belousov Zhabotinsky reaction, Benard's convection cells, galaxies formation [24], [25], [32]. Similar self-organizing processes exist nevertheless in the biological world. Epileptic fits and heart fibrillation are self-organizing reactions.

Self-organization shows the characteristic emergence of a spatial order, made of whirls and spirals. The appearing order also has a specific temporal organization that is different, both from the system-environment interactions and from the physicochemical interactions between constituents, here particles or cells. Those processes have a fundamental structural identity together with the flexibility and fluctuations of adaptation mechanisms. Those structures spontaneously develop. Moreover, they are persistent, resilient, self-propagating and self-replicative, for a while, after which they vanish. An attenuated replica generally follows them. They present oscillations in a cyclic evolution that reveals the presence of a three states of transition process (active, inactive, quiescent), which is the signature of self-organization. Their principles remain structurally stable, almost irreversible, and reproducible as universal attraction rules. The process is not chaotic because the principle includes reproducibility of causes and effects.

Self-organization is a crucial property of certain ordering mechanisms, which don't seem initiated by natural selection, but rather spontaneously present in the universe. This implies either to reject the Neo-

Darwinian dogma according to which genes are the support of evolution or to resort to the early universal Darwinism. In this later case, increases of complexity come from chance encounter between structurally stable phenomena that belong to different levels of evolution. Self-organization and natural selection combine together. They cooperate to intensify evolution's efficacy. Adaptation thus provides a means to take self-organizing opportunities acting as attractors, to drive random variation towards efficient forms of organization. This avoids the needle in a haystack problem and enables natural selection to run across the hills and valleys of a varied landscape to find basins of attractors, where it is easy to fall. Indeed, self-organizing processes are not very brittle. Their wide range of diversity, their spontaneous arising, the structured emergence of their organization states, as well as the broad spectrum of the initial conditions for their triggering, seem to indicate that attraction basins constitute wide and numerous areas in the state space.

2.3 NEURAL DARWINISM

In G. Edelman's Neural Darwinism theory, brain itself creates perception. It self-organizes on the basis of experience, *i.e.* the history and context of its own development. Monozygotic twins have the same genes, but not the same mind. Neurons are continuously submitted to selective pressure. The strength of the connections that represent the most appropriately the external world are reinforced. Neuron clusters interact. They permanently recombine to map the world in the strength of their links. CNS generates its own rules and categories. Recollection does not exist. Imaginary productions are reconstructed by generalization. Brain develops by a Darwinian selection process that takes place at the neuron groups' level instead of the individual neuron. The basic organizational entity is the cortical map. Maps are linked either with captors or with other maps.

The Neural Darwinism theory relies on Searle's theory of perception categories formation [35]. The functioning of the brain strictly relates to physics and biology. The matter-consciousness duality doesn't exist. Consciousness is an ordinary biological state. The relation between mental states and the underlying processes is not a causal factual chronology between distinct elements. It is the instantiation of a feature of the system that comes into being from a resonance between sensations and a mental state. Mental states are singularities, specific to the individual who feels them. Sensations, albeit supported by objective processes, quantifiable physically and chemically, are singular

specific qualitative mental states.

2.4 EMERGENT EVOLUTION

Emergent evolution generalizes this standpoint. Mind and brain are simply two different ways to consider a unique entity. Learning is the adaptive process. Sense is a match of patterns and therefore a unique realization. Mental states are processes found in the brain of higher vertebrates. These processes emerge from the elementary components of the brain. The link between mind and brain is simply the set of relational interactions between different subsystems in the brain [37]. Life, consciousness as well as other properties just appeared in an unpredictable way through rearrangements of pre-existing entities. The slow and gradual derive of a structuring variability generalizes evolution as applicable to many — not to say every — domain(s) and at various levels.

Exchanges between units are entirely deterministic. The activation rule sets their possible states. Under the pressure of random relations between the system and the external world, new structures emerge. Internal retroaction loops make them take roots into the existing structure. The system enters a permanent restructuring derive that makes (let) new properties emerge. The system thereby enters in a productive action of itself.

Learning and recognition are the constitutive bases of its own experience. The system state is fundamental to select information in the world. It learns what it recognizes, what comes to interfere with a stable state. Learning then brings the system back to equilibrium.

3. INTERNALIZATION PROCESS

Besides environmental pressure, there is obviously a social dimension in learning. A world involving a single entity seems highly unlikely to occur. Knowledge transmission leads to cultural evolution. The transmission process implies a double being, a relation to otherness. Groups of entities, or clusters at the cell level, tend to gather when they share a sufficient amount of features in a common space of similarity. Clustering is a dynamic process by means of which the structure permanently reorganizes in order for the new system to become the system itself. Clustering can be seen as more or less similar to the Darwinian reproduction-based speciation in terms of constituting cooperative/competitive groups of entities. The crucial point to favor clustering (or classification) is the diffusion process, which is the passage from local to global of characteristic features in the similarity space.

3.1 HOLISTIC REALIZATION

Functional structuring is fundamentally holistic. Novelty always reveals a global increase of the milieu wherever it occurs, not only to push back the frontiers of our understanding, following a preconceived plan, but unpredictably, bringing the proof of an immanent creation, that overwhelms any outside specification [4].

Adaptive behaviors are not simply reducible to the sum of — or the difference between — individual compartments. They involve something more that can't be reached by means of some reverse engineering techniques, something that arises more than results, a temporary concomitance that triggers the matching of a transitory representation with the current global state of the system. The transitory representation is — in G. Cottrell's [9] denomination — a holon, *i.e.* an intricate combination of a percept and a process into a holistic realization. The key point is that evolution has progressively integrated the internalization process to itself. The acquisition process is learned as well. It has become part of the structure to the extent that perception is in fact expected on the basis of past learning.

Most of the actual learning algorithms exclusively model the acquisition aspect of learning. They skip the transmission part, as they provide no means to pass on what is learnt. Learning is a dual process. It interacts between both directions of a continuum. It is made of two opposite but complementary processes. To our knowledge, only Fuzzy ARTMAP [7] and the DHP [21] implement a similar kind of interaction, but it remains more in the spirit of a control of the acquisition process instead of an active transmission of knowledge.

3.2 NOVELTY DETECTION

Novel salient features trigger the acquisition process. According to H. Bergson [4], newness is another kind of order relying on the ability of mind to see things in a new light. Mind creates sense from temporally and actively gathered contents. Disorder, or chaos, doesn't come before (precede) reality. It is just the way we figure out what we don't know or understand. It is also, and more than anything, what change emanates from, a movement towards novelty and creation. Newness, as opposed to the static difference between order and disorder, is a dynamic differential process between two orders, or between two opposite tendencies towards two orders. It is a dual process between disorder and novelty regarding mind, and in the living world, two opposite processes that either build up a form by adapting the organic matter and thereby follow a creative impetus by means of those spatial transformations themselves [40].

Novelty enhances species' survival somehow, such as by favoring courtship behaviors and mating. The imitation process may have been selected by evolution to quickly compensate for individual loss of appeal when faced with innovative behavior.

Between wild animals, the transmission of innovative behaviors that brings selective advantage for reproduction or feeding has frequently been observed. Such a case is learning through imitation. Male whales in Australia change their songs every five years. The innovative song generalizes to the whole colony in the two following years. It is also well known that some kinds of more cultural or convenient habits, which don't seem at first sight related to selective pressure, can as well quickly spread over a population like fashion effects do. Macaque monkeys still wash their sweet potatoes at Koshima beach in Japan, since Imo, a young female, did in 1953. In this case, imitation seems to have the leading role in the process. The learner is not taught or trained at all. It actively enters the process to take possession of what appears to be new or different. The saliency of a sensory stimulus of discontinuous abrupt nature is suddenly perceived as contrasting with a continuous undifferentiated background.

What is true with sophisticated individuals in more or less elaborated species is also true at the cell level. In vitro culture of chicken embryonic heart cells have been shown to tune their beating frequency when submitted to repetitive electric shocks. Progressively, they adopt a new intermediate frequency halfway between their initial one and the frequency of the applied electric shocks.

3.3 RETROACTION LOOPS

There are two varieties of retroaction loops. They can be positive or negative. Negative retroaction is a weakening mechanism, while positive retroaction is an amplifying one. A retroaction process settles a feedback from the environment to the system, which thereby controls its action on the environment. Dynamic regulation is a consequence of the strength of the mutual interactions between components and tends to equilibrium.

In implementations, to each of those loops, correspond a process that the programmer translates in terms of heuristic choices. Unsupervised learning is driven by events that are significant enough to generate a structural evolution of the NNs in response to a change in the data distribution. Data driven programming together with error measures constitute self-supervision loops. An error—or cost—function brings this information back.

The external loop environment-system is represented by a measure of convergence. Global error accounts for convergence quality. For some

algorithms, the global error (statistical methods, MLP, etc.) is efficient. In SOM, neighborhood dynamic is the key in the encoding process of the topological ordering. A more sophisticated measure must then be drawn to account for local error.

The inter-structures (clusters) loop corresponds to the local error. It is coded by methods of insertion-suppression of the units. Local error reflects the topological ordering quality and thereby representational conflicts. Conflicts point out where the environmental pressure accumulates activity, as a consequence of an insufficient resolution of the representation zones.

The intra structure loop (between units) brings context states in terms of activation. It spreads activation towards neighboring units to propagate similarity features that gather units inside the clusters.

3.4 DIFFERENT TIME SCALES

Different separate and independent levels of evolution combine into a unique structuring process. To those levels, correspond retroaction loops that provide recursion to the process. To the main loops correspond temporal scales that characterize interactions between units, between units clusters and between the system and its environment. At an upper level, rules that govern these mechanisms also evolve on and by themselves. Learning thus appears as a dual process, which includes memorization and forgetting, and that unfolds at various time scales.

The process is intimately related to the time. The derive needs duration to set evolution in motion. In the time course, properties combine together to maintain and optimize the existing functionalities. What exists competes with what is new. Some properties tend to generalize. At the same time, persistently settled elements disappear. Disappearing functionalities resist. They spread their properties within the structure to maintain them. During dissipation, properties that subsist condense. They simplify and gain efficacy and abstraction. The most resistant features are attracted by structures including highly similar features into which they merge. Other features have less and less relations with the other components. They are rejected on collapsing structures. They become unused. They return to a quiescent state. Either they slowly degenerate and finally disappear, or events reactivate them. They can then recover efficacy and reincorporate into more active structures. They can even sometimes become (or become again) attractors and gather in a new structure features that they get from other structures with which they compete. This way, functionalities are restored into new optimized combinations. This local and global

roll of the structure combines what remains from what is becoming obsolete, together with what newness brings, in order to best represent the world. By introducing entelechy, units struggle to survive. Selection favors dominant features' survival. The strength of the connections that appropriately fit with the external world is reinforced. Complexity comes as this progressive building scheme settles in duration.

Times scales characterize at least three levels of dynamics. Exchanges between units arise at a very fast rhythm, almost instantaneous, in terms of competition, of activation states, of activation spread and memory actualization. Clusters reorganization is more progressive. It unfolds over short- or medium-term time intervals. Cooperating sub-nets of units assemble or diverge. Selection works. It creates. It suppresses. It exerts pressure on the structure. Over longer periods of time, adaptation cycles appear. The system begins to evaluate its capacity to represent its world. Episodes appear. A story builds. Links between events and sense or functionalities establish. Others disappear.

Finally, the time axis is irreversible. The system is not dissociable from its history and its history is a single realization. The temporal succession of the constructive episodes shapes a structure anchored in the unfolding of its own instantiations (Varela's enaction or Brook's embodiment). The structure is both perceptive and reactive. Reactions are the fruit of perceptions and perceptions are themselves reactive. Present updates the past and past instantiates the present. This way, the system can exhibit a comportment by means of which certain features, which have existed before, but disappeared a long time ago can suddenly reappear after a quiescence time that can last over very long periods.

4. HOLISTIC EMERGENCE

Albeit still fiercely discussed, holistic emergence allows to account for structures arising, transformation, and vanishing, in a wide range of domains. Would it only be a convenient transitory working hypothesis, designed to draw the line from where we leave aside our lack of knowledge when faced to complexity, we will make the assumption that there exists an ascending encoding scheme and further concentrate on the review of a couple of questions inherent to this view.

4.1 EMERGENCE VS. SYMBOLIC APPROACH

Resultant phenomena are accessible analytically. Conversely, emergent ones are not merely understandable from the study of their elementary constituents. Morgan [30] considers evolution, from

inorganic matter to man, as a reorganization of the relations between entities into more and more complex structures. Progressively, structures interlink to become more and more intricate into higher organization levels (electrons, atoms, molecules, cells, organs, organisms). Each step being characterized by new properties which in turn constrain events in the inferior levels.

To specify our position, regarding the top down approach, we will refer to I. Prigogine [33] who doesn't reject reductionism as such, but points out its limitations. In essence, for him, reductionism can be efficient in relatively simple situations, but quickly becomes ineffective as soon as the number of factors to consider is important. If we consider a few organization steps ranking from molecules, neurons, neural networks, brain to mental states, nobody could explain the latest based on an analysis of the interactions in the former. The fact remains between two more closely related organization levels like neurons and neural networks. Even though the increasing power of medical imagery now permits deeper investigations, to set the matters straight, we have only found complexity so far. Therefore, we still must resort to modeling and computing simulation, would it be only a complementary spoonful approximation, to try to figure out how the brain's structures assemble and cooperate.

In traditional cognitivist AI, the top down approach is directly related to the obvious requirement to fit logic formalism needs and its claims to universality, namely symbols' sense and form sharing and the innate assumption [2], [37]. Another drawback is that *a priori* specified symbols, rules and therefore representations are not autonomous. In the living world, they can gradually vary in time in different ways, and not only in terms of membership strength as covered by K. Zadeh's fuzzy logic. Rules are everything but static. They change in the course of development [2], [37], [38]. What has always been pertinent until now can become detrimental, either suddenly or progressively. One striking example is graft reject by the immune system. Additionally, emergence constitutes a contradiction for traditional logic. In an organization level, the appearance of new properties, which were neither present nor predictable in lower levels, cannot be taken into account. The symbolic computational model is a closed system of rules operating only on the symbols. Moreover, inference rules for symbol's manipulation are applied sequentially. And last but not the least, the interpretation of the symbols is not intrinsic to the system. It is the programmer, as a *deus ex machina*, that makes it.

According to F. Varela, it is the structural coupling history that enacts (makes emerge) a world

by means of a network of interconnected elements, capable of structural changes in the course of a non-interrupted history. Symbols, in the conventional sense of the word, are excluded. Significant elements are not the symbols but complex patterns of activity between the multiple elements of the network. Varela just discards the cognitivist axiom according to which cognitive phenomena explanation requires a distinct symbolic level. Sense is not enclosed inside symbols. It appears as a function of the global state of the system and remains closely related to the general activities that are recognition and learning.

4.2 ENTELECHY

To our knowledge, everything in the universe is finite in the sense that it has a lifetime. If we want artificial systems to exhibit properties similar to those of living beings, it seems essential that they should include their own end. In order to endow NNs with an artificial vital impetus, nodes must have a restricted life span.

Darwinian selection doesn't favor perfection, but efficacy. Winner-take-all (WTA) NN models present the advantage of allowing a fitness function at the unit level. Nodes the links of which have less strength can thus easily be eliminated. This reinforces the survival of the fittest scheme. A converse mechanism must maintain links' survival. The system can thus remember (strengthen) good relations while forgetting (weakening) bad ones. The three main approaches used to optimize the size of NNs can be summarized as constructive (incremental), reductive (pruning), and evolutionary (mostly genetic algorithms (GA) and their combination with NNs) [39].

In accordance with the general approach developed here, we have chosen a dual process alternating between creation and suppression. Suppression is controlled by the local error (a measure of the topological ordering) among neighboring units. New units are added by a meiosis growth or totipotent stem cells (SCs) proliferation inspired mechanism, which acts at the unit level, as if its memory vector was a phenotype.

4.3 NEUROGENESIS

Neurons, and more generally cells duplication in nature can take three forms that are meiosis, mitosis or stem cells. Those replication schemes are more or less elaborated and participate to any step of organic specification, from the most general to the extreme specificity.

Meiosis is an equitable process, by which growth generates diversity. Duplication recombines the genetic material by crossover. The process thereby

differentiates resulting daughter cells from the initial ones. Mitosis is only a multiplicative process. New cells are absolutely alike the original. SCs have three main properties that are their ability to proliferate, to migrate and to differentiate. SCs in human are from prenatal or postnatal origin. Postnatal (adult) SCs are available from the umbilical cord, placental tissues, and most of the corporal tissues. Prenatal SCs are available from embryos (4-7 days) and foetal tissue.

SCs' differentiation potential is wide and progressively restrictive as specialization increases. Possible differentiation ranges from totipotent, pluripotent multipotent, to unipotent. Totipotent SCs can potentially recreate a new complete embryo. They differentiate into any postnatal and extra embryonic tissue. Pluripotent SCs are able to generate most —not to say every — of the tissues in the adult organism. Multipotent SCs can provide several cell types. Unipotent SCs (precursors) can only generate one kind of cell [31]. Areas in the adult CNS of mammalian and human contain pools of quiescent multipotent neural stem cells (NSCs) in reserve [1]. Multipotent NSCs, can differentiate into any kind of cell in the NCS (neurons, astrocytes and oligodendrocytes). Differentiation arises while NSCs migrate to find their target.

Migration constitutes a hierarchical flexible network that includes various multistep possible reversible changes of expression (Fig.1). Cells precursor's progenitors can be reprogrammed (reverse broken lines in Fig.1). They may go backwards steps to change their final expression as well as to return to proliferating states (solid and broken circular lines) where they self-renew. They can replace local or distributed targeted neuron clusters.

Grafted human NSCs survive in the brain, and take over the function of lost neurons. In [16] modified stem cells² naturally migrate in vivo across the brain, towards multiple targets, to successfully track and treat areas damaged by tumors with numerous satellites. Precise migration can cover long distance inside the brain, even along nonstereotypical migratory routes [15]. Inflammation, or similar general perturbation mechanisms characterizing many pathologies, diffuse molecular recruiting stimuli that provide pathways for migration and final homing. Final differentiation steps are not reversible and occur according to the specificity of the neighboring cells. Transplantation of NSCs, either from in vitro culture or from heterotopic endogenous origin, shows remarkable survival and differentiation into site-specific neurons.

² Adding a gene that made the cells express TRAIL antitumour molecule.

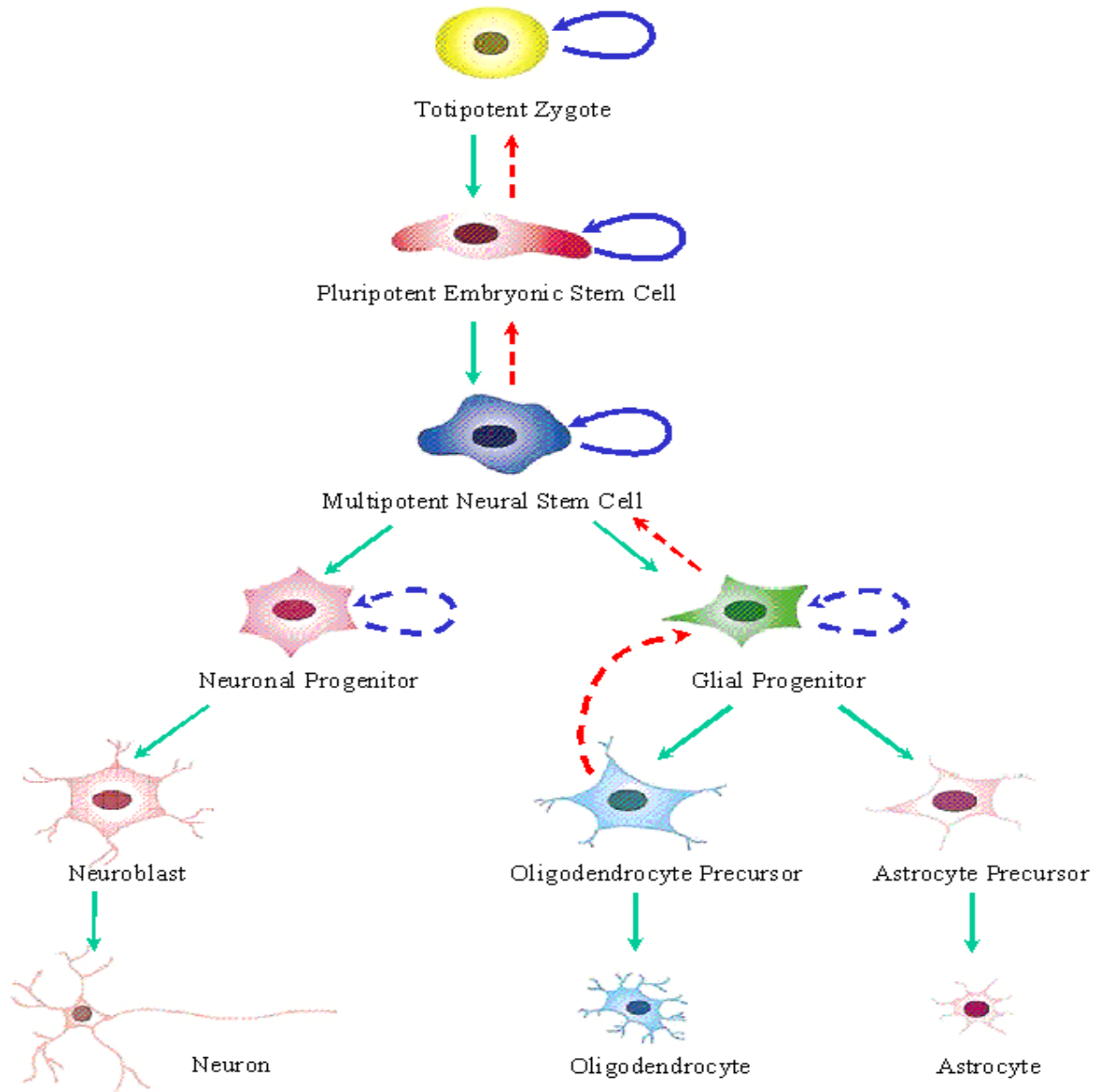


Fig. 1 – Stem cells and precursors hierarchy. Reproduced from [1].

Proliferation of quiescent NSCs is triggered by the general perturbation mechanisms (inflammation) [15] that indicate the migratory pathways and are common to many kinds of pathologies.

Moreover, SCs bypass the species frontier. Successful embryonic NSCs transplants between human and monkey, mice or rat in [17] demonstrate that NSCs can survive, correctly differentiate from human's to mammal's neurons and incorporate the site-specific brain structure, including gene expression.

In growing models related to the SOM algorithm, the duplication dynamic is generally mitosis inspired. To realize meiosis growth, when we initialize new cell's weights, we insert a trace of the triggering data prototype together with a trace of the features gathered in the relational neighborhood of

the mother cell, the daughter cell splits from. Immediately after, the daughter cell enters the process of migrating towards the most related cells inside the whole system. This is achieved by re-computing the widest neighborhood tree possible.

4.4 INNATE STRUCTURE IMPORTANCE

A further aspect that plays a key role is the size and modularity of the initial structure. In neural computing we usually proceed by trials and errors to determine an appropriate size of the network for a given application. Biological functional representations are somewhat more sophisticated. They are located over non-contiguous regions that interact to lead to some more elaborated states than a simple summation. Moreover, brain areas involved in a peculiar function can have multiple

participations into other functionalities encoding.

Among inherited brain disorders, a rare genetic disease, the William's syndrome (WS), generates peculiar effects on astonishingly spontaneous savant-like musical abilities of the affected people. Their brain organization seems to indicate that there exists an encoding schema not only relying on the number of units devoted to one functionality, but also on the ratio between the respective proportions of the various neural clusters which participate in functions encoding and the whole size of the rest of the brain.

WS appears in every population with a prevalence of about 1/25,000 live births. Affected people show serious neurological and neurophysiological developmental troubles associated with a special brain organization [23]. They hardly carry out very simple visuo-spatial coordination tasks (walk, lace up shoes, use knives and forks, ...). Spatial organization tests show a selective attention to details, regardless of the whole. Despite a general deficit of spatial and cognitive functions, their linguistic capacities stay partly preserved [3]. They talk easily but their speech, albeit rich semantically, sometimes proves to be absurd.

Surprisingly, WS persons spontaneously exhibit auditory hypersensitivity and uncommon musical skills, very unusual in confirmed musicians (absolute pitch, complex rhythms reproduction, rhythmic dialogues production). People with absolute pitch memorize sound height while those with relative pitch memorize intervals. Absolute pitch offers the advantage of no reference point needs (diapason). Actually³, the European reference is an A at 440 hertz. People with relative pitch identify sounds' height based on this reference. Interval-organized memory is more suited for height variations of the diapason. Any reference change shifts all the notes the same way. In addition, ageing modifies hearing. The reference is less and less accurately perceived. Height-organized music sound perception prevents chords synthetic appreciations or intervals. Both must then be computed.

Anatomically, WS subjects' limbic, frontal and temporal structures remain relatively preserved compared to the mean size observed in non-affected people. The interesting fact is that musicians generally present an oversized region in the temporal lobe. WS affected people's brain is globally undersized by an amount of about 30 %, but the size of the same zone in the temporal lobe is normal. The proportion between this zone and the rest of the brain seems to encode their unusual musical skills.

5. STRUCTURAL PLASTICITY

Brain's developmental plasticity results from a slow gradual iterative process of progressive specialization. It can nevertheless prove to be capable of rapid developmental and experience-based plasticity.

Profusion and diversity of the living species demonstrate the universal plasticity of brain structuring. Change in shape and wiring affects neuronal growth and development, at almost every level in the brain. Reorganization occurs during learning, to establish spatiotemporal correlations between percepts, built from sensory origin, and their projections in the brain structures. The process is a real coevolution between the organism and the milieu it interacts with. Brain organization and plasticity rely on its capacity to re-model and reconfigure neural wiring. Various underlying mechanisms contribute to reinforce links and structures. Those mechanisms can stimulate dynamic growth of new synapses, create new neurons [22], trigger growth or shrinking and even redeployment of cortical maps. Furthermore, the size of the functional structures, as well as the amount of potential exchanges reveal architectural constraints of interdependency that play a key role in encoding. Processes are dual. Decreasing always counterbalances increasing.

5.1 AT THE SYNAPTIC LEVEL

Both the number of units as well as their branching connections is not regular and thus cannot be specified in advance. Specialization leads to a volume increase of the concerned regions.

Long-term potentiation (LTP) is a prolonged increase of the synapses' efficiency due to high frequency stimulations. It has three properties. It is cooperative, associative and specific to the stimulated junction. LTP results from a backward diffusion from the target neuron towards the source neuron. It can modify the synapses' form and size, and recruit inactive synapses in the neighborhood. It can even trigger the growth of new synapses, insert new receptors or set in motion the genetic machinery to grow new neurons from a population of progenitor cells (see Fig.1) that migrate and differentiate into neurons.

LTP can arise within a few dozens of milliseconds and persist during weeks, or even months [22]. It is learning induced and most of the reorganization arises within the half hour following induction. The mechanism seems to self-regulate to avoid saturation. A converse long-term depression (LTD), acts to compensate for increases of activity. While some synapses are reinforced, others are weakened.

³ Historically, until the 19 th century, each important town in Europe had its own diapason.

In addition this confirms the existence of retroaction loops at the synapse level. Those properties demonstrate Hebb's rule validity, which postulates that synaptic efficiency is adjusted based on coincident pre- and post-synaptic activity. Constraints of interdependency between the converse processes of the LTP/LTD mechanism suggest the plausibility of a redistribution of a finite amount of activity inside the brain. PLT plasticity doesn't seem ageing dependent. Neurogenesis was confirmed for humans from 57 to 72 years old [12]. Moreover, learning increases new neurons' survival.

5.2 AT THE UNIT LEVEL

As well as being synaptic efficiency dependent, functional change is also determined by the number of active neurons. [41] reports investigation of structural plasticity at the neuron level in the center of memory and learning in fruit flies' brain. This center is located in a small cluster of about 5,000 neurons, and thus allows precise observation. Growth, guidance and branching occur in a sequence of discrete steps under control of three genes (Rac genes), found in the DNA of all species. Those genes produce proteins (Rac GTPases) with a rather identical molecular structure, from fruit flies to humans. Results indicate that cells' steps of development correspond to gradually increasing amounts of protein from relatively small for growth, medium for guidance, and large for proper branching. The sequence of events begins by sending out an axon from the neuron, while several dendrites carry impulses back to this neuron. The axon then migrates towards its target, and dendrites undergo extensive growth and branching.

5.3 AT THE CORTICAL MAPS LEVEL

The size of the cortical region devoted to functional representations reflects their sensorial importance. Size varies depending on species and evolves among individuals. Cortical areas permanently increase or shrink, depending on system-environment interactions.

Experiments carried out on monkeys show that learning induces very short-term broad reorganization of cortical maps for fingers in the motor cortex. Extensive use of a specific finger (a few hours are enough), cause an increase of its cortical representation area. Conversely, preventing fingers' use reduces the size of their corresponding maps.

Moreover, there is an obvious conformity between experimental visual patterns and the retinotopic organization of their projection in the visual cortical maps [36]. The receptive fields' size and overlap tuning is shown to be retinotopic-

organized as well.

5.4 AT THE CORTEX LEVEL

The cortex of higher vertebrates— and especially humans — has evolved as a gradual adaptation of the structure in accordance with function change. Considering the phylogenic evolution of the central nervous system (CNS) in an interspecies paradigm reveals that structure's modification follows architectural constraints. When new structures appear (neo-cortex), they are not simply added to the previous ones. The whole size of the brain does not change according to the size of the new part. Pre-existing parts, which were devoted to other functions, are also utilized and fed into the new structure. An increase in a zone is correlated to the diminution of other parts of the brain.

A study of brain structures' interdependence during evolution [8] states that the neocortex increase in volume is proportional to the decrease in size of other brain structures (medulla, mesencephalon, diencephalon). The cerebellum, where orientation and balance centers are located in, has a relative volume that accounts for 13 % of the total volume of the brain among the majority of the mammals. It increases in bats and Cetacea. Conversely, the neocortex, that plays a major role in complex cognitive functions, only accounts for 28 % of insectivores' brain against 81 % in primates.

6. FUNCTIONAL REDEPLOYMENT

Recent extensive use of imagery techniques like nuclear magnetic resonance (NMR), positron emission tomography (PET) and functional magnetic resonance imaging (fMRI) allows a deeper exploration of the functional neuroanatomy of cognitive functions. Study of brain reorganization in humans with sensory deprivation, either of congenital or traumatic origin indicates further aspects of adult neuronal plasticity. Profound permanent reorganizations take place, but they are not irrevocable.

6.1 REORGANIZATION

Areas corresponding to unused functionalities are recruited to represent other functions that can be represented in spatially close structures or in more distant ones.

In [34] the occipital cortex of congenitally blind humans activates during verbal memory tasks. Activation was found in regions along and inside the calcarine sulcus corresponding to the retinotopic visual areas of sighted humans, including the main primary visual area (V1). No such occipital activation has ever been found in sighted humans.

The study concludes that visual areas in the posterior occipital cortex (including V1) of congenitally blind is likely to be involved in episodic retrieval.

The study of the neural organization of auditory structures in congenitally deaf adults [11] confirms that neural reorganization involves a redeployment of unused structures. Degeneration in the central auditory system follows profound hearing loss. Cell size reductions appear in the cochlear nucleus. Surprisingly, in case of deprivation from birth, the sub-cortical projections to the primary auditory cortex remain active. Cortical auditory regions continue to receive input from sub-cortical regions and don't exhibit degeneration. However, functional changes in synaptic activity and in organization within the auditory cortex suggest a possible variation of the structure as a consequence of congenital deafness. Neurons within the Heschel gyrus and auditory association cortex do not degenerate because they respond to non-auditory stimuli. Responses to both tactile and visual inputs have been reported in auditory cortex of congenitally deaf individuals.

6.2 REVERSIBILITY

Another characteristic is that once developed and clearly established, should the representational structure become unused, it progressively diminishes in time but not entirely. There remains a part from which the representation can be restored.

The first transplant of the two forearms in human, allowed a quasi real time access to cortical sensory motor projection maps reorganization four years after amputation [13].

On the Penfield's motor homunculus hands' mapping is spatially close to the face area. Fig.2 and Fig.3 show a digital reconstruction of the various steps of the hands and elbows projection maps' shrinking between the amputation and the transplant, together with the shifts of their centers of gravity. The re-colonization process clearly appears after transplant. In the interval, the face representation area, which is close to the hands' map, considerably expanded to colonize the zones left unused by the reduction of the hands projection maps in the motor cortex.

Reversibility can occur over far longer periods of time. Albeit artificially triggered, an example is brought by phylogenic evolution. The chicken would have had teeth and lost them 80 million years ago when birds differentiated from dinosaurs. In a recent experiment on mutations in chicken [14], this feature, which had disappeared with evolution, reappeared. Chick embryos with saurian-type teeth were obtained.

Activation areas for hands cortical projection maps

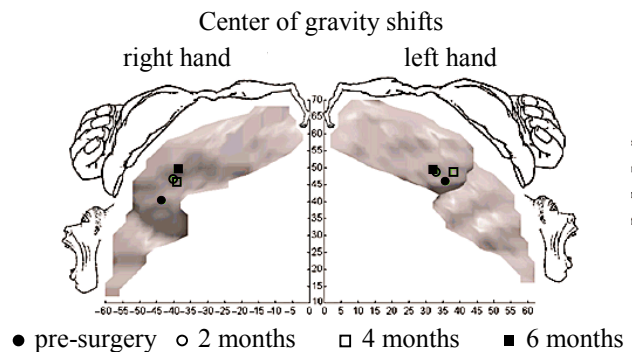
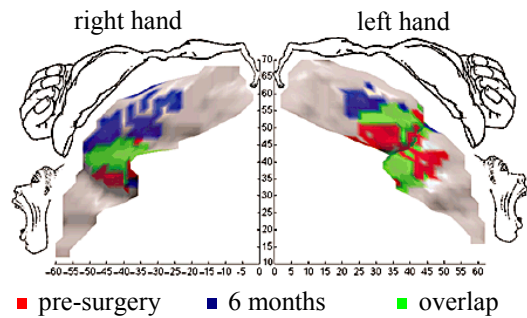


Fig.2 – Hands activation motor cortex and shifts of their center of gravity. Reproduced from [13] by courtesy of A. Sirigu and Nature Neuroscience.

Activation areas for elbows cortical projection maps

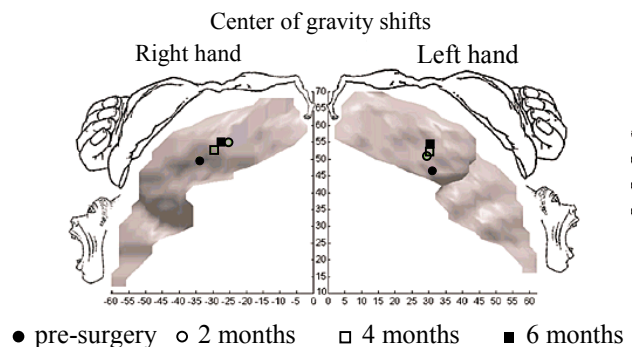
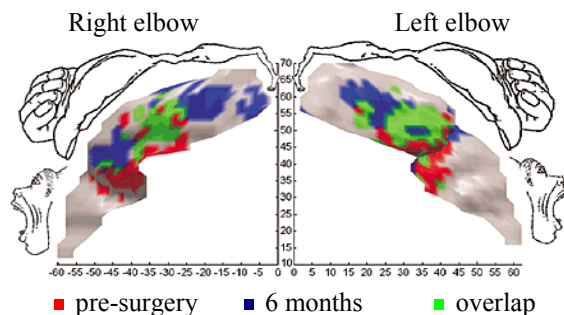


Fig.3 – Elbows activation motor cortex and shifts of their center of gravity. Reproduced from [13] by courtesy of A. Sirigu and Nature Neuroscience.

7. CONCLUDING REMARKS

With regard to the possible states in a data space, NNs learning algorithms create (find) an attraction basin. The attraction potential of this state manifests through its generalization capability. Such a learning nevertheless constitutes a discrete instantiation, limited to the perception of one state among a multiplicity of possible states. The NN only extracts a static image of the environment. Generalization is strictly limited to highly similar images. Any further learning can only constitute another distinct instantiation, without any link with the previous one(s). Actual NNs do not apprehend the relations between various transitory instantiations of similar states. They do not combine these isolated experiences into a global one. There is no continuity. Those systems are highly organized but they are not able to integrate a series of experiences to selectively build new knowledge from former knowledge.

Throughout this paper, we —non-exhaustively— reviewed some essential properties observed in the development of encoding structures in nature. Studying the process by which new structures can emerge in artificial unsupervised NNs models amounts to incorporate a control dynamic of their evolution to the learning algorithms. To the extent that we clearly affiliate to the theoretical frame according to which natural systems that spontaneously perform adaptive learning subsume into the principles of the evolution theory, it is of prime importance to understand and to model the various underlying processes and try to set them in motion.

Darwinian natural selection can occur in any group of elements holding three elementary properties, which are reproduction, slight variation and a transmission mechanism between the reproduction cycles. The elementary components of a minimal developmental adaptive system are thus a random diversity generator, a sort (selection) and a dissipative structure. Positive and negative retroaction loops relate them. The preceding revue brings out duality as an essential general property of the adaptive processes of natural organization involved in evolution. Those processes are two by two opponents but complementary (eg the competition loop between either meiosis- or totipotent SCs-based growth and cellular death). It seems that duplications of the same dual process entangle at various levels to carry out the structural reorganization as well as to grasp and integrate the features that former knowledge can relate to perceptions.

The process of natural organization we consider here doesn't only involve system-system and system-

environment regulation control. It is somewhat more sophisticated in that it takes into account dynamic interactions that contribute to enhance the system self-producing capability. It is closer to recursion in the sense of an organizational dynamic interaction, where the output retroacts on its former process to incorporate itself into the originating process it emanates from, to end up as the new former process of the system. To implement this process, we create an upper level duality loop into the system. We thereby try to integrate a self-learned teaching-learning loop. The system could thus adapt from the basis of the complementary between learning to teach and teaching to learn. It would henceforth become possible to develop really autonomous tools that automatically initialize, learn permanently and forget when necessary, while accordingly adapting their structure.

Further developments include experimental evaluations to complete the implementation of the Darwinian evolution process and the underlying processes to improve the model. We try to proceed in an adaptive cumulative manner. The idea is to start small both regarding the architectural configuration and the learning contents. One direction is to try to learn the various rules that control the neighborhood parameter in SOM. Another point of interest is to look if the uncommitted cells in SOM, which may correspond to intermediary steps of organization, could be used as a SCs reserve and whether they could constitute a pre-learned basis from which further learning could start instead of starting *tabula rasa*.

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